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FABRICATION OF BERYLLIUM-CLAD TUBULAR HYPERVELOCITY IMPACT TARGETS BY GAS PRESSURE BONDING

by

R. J. Diersing, H. D. Hanes, and E. S. Hodge

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY REPORT

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SUMMARY

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A

Beryllium armor was gas-pressure bonded to tubular liners to provide hypervelocity impact targets. Target size was 6 inches long by 1.220 inches in diameter of beryllium over 0.500-in.-OD Type 316 stainless steel or niobium-1 percent zirconium alloy having nominal wall thicknesses of 10, 25, and 40 mils. The beryllium was either hydrostatically pressed from QMV powder or fabricated from PX20 extruded and annealed beryllium tubing. Gas-pressure-bonding conditions of 1400°F for 1 hour at 10,000 psi were utilized to densify and bond the beryllium to the stainless steel or niobium liner tubes. Author

INTRODUCTION

The gas-pressure-bonding process was investigated as a fabrication technique for producing tubular beryllium-clad stainless steel and niobium hypervelocity impact targets. These impact targets were 6 inches in length by 1.220-in. diameter of beryllium over 0.500-in. OD Type 316 stainless steel or niobium-1 percent zirconium alloy tubing having nominal wall thicknesses of 10, 25, and 40 mils. Several beryllium test bars 3/8 inches in diameter x 6 inches long were processed under the same conditions from the same starting materials as the targets. They were intended for use in subsequent material property determinations.

The beryllium portion of the target was fabricated either from QMV powder hydrostatically pressed to the desired tubular shape or from extruded and annealed beryllium tubing. Bonding of the beryllium to the stainless steel or niobium liner tubes was accomplished by gas-pressure bonding at 1400°F for 1 hour at 10,000 psi. This process involves the application of heat and pressure to specimens to densify and bond the beryllium to the tubing.

This investigation was directly associated with the procurement of hypervelocity impact targets. The details presented in this report document the fabrication of the targets. No attempts were made to analyze the bonds produced or optimize the bonding parameters.

MATERIALS

Two different types of beryllium were employed in the fabrication of the hypervelocity targets. The QMV-grade powder was supplied by the Brush Beryllium Company. Table 1 is the certified analysis of the powder supplied by Brush. The other type of beryllium was hot-pressed, extruded, and annealed PX20-grade beryllium tubing fabricated by the Beryllium Corporation to 1-1/4-in. OD by 1/2-in. ID by 6-in. lengths prior to pressure bonding. Table 2 lists an analysis of the tubing as supplied by the Beryllium Corporation.

EXPERIMENTAL PROCEDURE

Two different methods were investigated for the fabrication of the beryllium clad employed in the hypervelocity targets. QMV grade powder was cold hydrostatically pressed and then machined to the desired size before gas-pressure bonding to the stainless steel or niobium tubing. In the other method, hot-pressed, extruded, and annealed PX20-grade beryllium was fabricated at the Beryllium Corporation to the desired size before specimen assembly and gas-pressure bonding.

Assembly of Tubes From Hydrostatically Pressed QMV Beryllium Powder

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Beryllium QMV powder was cold hydrostatically pressed at 60,000 psi over the stainless steel or niobium tubing to the desired cylindrical shape. Figure 1 is a photograph of the components employed during the assembly of the specimen prior to hydrostatic pressing. Gooch rubber tubing was stretched inside a metal preform and turned over on each end. A mild steel mandrel was machined to fit inside the Type 316 stainless steel or niobium-1 zirconium tube and two mild steel wheels were used to center the liner tubing on the loading container. This assembly was then slipped into the rubber preform as illustrated in Figure 2. The small rubber bands hold the components in place. A rubber stopper was glued into one end of the preform, sealing this end of the specimen. Then beryllium powder was vibratory packed into the assembly. The upper spacer with the holes drilled in it was then replaced with a solid wheel, and a rubber stopper glued in this end. The remaining length of Gooch tubing was stretched over this assembly and sealed in preparation for hydrostatic pressing. As a final precaution against rupture of the Gooch tubing during hydrostatic pressing, a second length of Gooch tubing was stretched over the assembly and sealed. Each specimen assembled in this manner was hydrostatically pressed at 60,000 psi. After pressing, the rubber stoppers and Gooch tubing were cut from the specimen and the metal preform removed. Figure 3 illustrates a specimen after hydrostatic pressing.

The mild steel wheels were not removed from the specimen until machining to final size prior to pressure bonding. After rough machining, the specimen was canned in mild steel. Stainless steel end plugs were welded in each end in an inert atmosphere to seal the specimen. An evacuation stem of 1/8-in.-diameter stainless steel tubing was welded into one of the end plugs to evacuate the specimen to 10 microns prior to gas-pressure bonding. This evacuation stem was sealed while the specimen was under a vacuum. Figure 4 is a photograph of the specimen prior to pressure bonding.

Assembly of Tubes From PX20 Extruded Beryllium

Beryllium tube targets were also assembled from hot-pressed, extruded, and annealed PX20 beryllium tubes 1-1/4-in.-OD by 1/2-in.-ID by 6 inches long supplied by the Beryllium Corporation. In Figure 5, the components necessary for the assembly of the targets fabricated from the extruded beryllium are shown. A mild steel mandrel was machined to fit inside the stainless steel or niobium tubing. The mandrel and tube were fitted inside the 1/2-in.-diameter hole in the extruded beryllium section, which in turn was sealed in a mild steel can as previously described.

Gas-Pressure Bonding

The tube targets and test bars were gas-pressure bonded for 1 hour at 1400°F at a pressure of 10,000 psi. A minimum pressure of 1000 psi was applied at 200°F and then increased simultaneously with the temperature.

The bonding temperature varied between 1375 and 1430°F. Two of the targets did not achieve full density because leaks developed during the gas-pressure bonding cycle.

Decanning of Targets

The steel cans were removed from the targets by pickling in an aqueous 50 volume percent nitric acid solution. The temperature of the bath was maintained at 160°F. The mild steel mandrels inside the stainless steel or niobium tubing were not readily removed by pickling so drilling of the mandrels and then repickling was necessary to remove them.

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Machining and Cutting

The hypervelocity targets were machined and hand polished to 1.220-in. OD as illustrated in Figure 6. One-half of the targets of each item were cut in half to 3 inches to fit a hypervelocity testing apparatus. Several targets of Item 3 and 6 were etched after final machining to remove the microscopic surface irregularities induced by the machining operation. Approximately 5 mils of material was removed by etching in a solution of 5 weight percent H_2SO_4, 75 weight percent H_3PO_4, 7 weight percent Cr_2O_3, the balance water. The solution temperature was maintained between 120 and 130°F.

RESULTS

Beryllium tubular targets and cylindrical test bars were fabricated by the gas-pressure bonding process described herein. The targets were 0.5-in. ID by 1.5-in. OD by 6 in. in length and the test bars were 0.375 in. in diameter by 6 in. in length. Table 3 lists the coding of samples sent to NASA. The appearance of the deformed mild steel cans indicated that densification of the hydrostatically pressed and extruded beryllium had taken place. Visual examination of the beryllium target after removal of the mild steel can and mandrel by the nitric acid pickle revealed a slight bowing in the hydrostatically pressed beryllium targets. As a result, after final machining and polishing, the outside diameter of the specimen was concentric with the ends and straight, while the bore was bowed. The machined and polished surface on the targets was quite satisfactory, and most diameters finished to 1.220 inch after polishing. Three targets, two of Item 4 and one of Item 5, were of diameters of less than 1.220 in. Three targets, one each of Items 8, 9, and 10, did not achieve full density due to a leak in the can during the gas-pressure-bonding cycle. Two targets of Item 9 had a longitudinal crack along the outside length of each target.

Two targets of Item 3 and two of Item 6 were etched after final machining to remove surface finishing effects. The targets of Item 6 were masked off on the ends to prevent excessive attack of the beryllium at the liner armor interface.

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Eight test bars were machined to a size of 3/8 in. by 6 in. in length. Four test bars were machined from the hot-pressed and extruded beryllium and four from the hydrostatically pressed beryllium. The diameters of the test bars machined from the pressed beryllium powder were less than 3/8 in. in diameter. One of these test bars broke into two parts while machining.

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DISCUSSION OF RESULTS

Hydrostatically Pressed Beryllium Targets

A tendency for the hydrostatically pressed beryllium tube targets to bow during the hydrostatic pressing at 60,000 psi was a major problem. In most of the targets fabricated in this manner the bowing was slight. However, in several of the pressed targets, the bowing was appreciable. Probably the beryllium powder was not loaded evenly around the stainless steel or niobium tubing and mandrel. During hydrostatic pressing the target densified more uniformly in some instances, while in others it did not. Also, the mandrel supporting the liner tube was loaded on the ends by the rubber stopper causing longitudinal camber. Some allowance should be made in future samples to allow the rubber stoppers to move along the rods during densification.

Prior to gas-pressure bonding, the hydrostatically pressed beryllium targets were machined to fit the cans. This uneven loading of the powder left depressions near the ends of the specimen after machining for canning.

Hot-Pressed, Extruded Beryllium Targets

The beryllium armor for these targets was received from Berylco machined to fit the outside can and slip over the tubing and mandrel. A slight bowing tendency was observed in a few of these targets. This was, however, to a lesser degree than on the hydrostatically pressed powder beryllium targets.

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Decanning and Machining of the Targets to Final Size

The nitric acid bath used to remove the mild steel cans from the specimens after gas-pressure bonding was very effective and did not etch or attack the surfaces of the beryllium, the stainless steel, or the niobium tubing. However, the attack of the acid on the mild steel mandrel through the center of the target was quite slow. This necessitated drilling out the mandrel to speed up removal. This method proved successful.

After machining to a diameter of 1.250 inches, some of the targets exhibited slight indentations in the surface. This was remedied by machining and polishing to a diameter of 1.220 inches. Not enough beryllium stock was present during initial assembly of the targets that were either hydrostatically pressed or hot pressed and extruded to shape.

The etchant (refer page 5) employed to remove 3 to 5 mils of the beryllium to improve surface finish was very satisfactory. The etchant had a tendency to penetrate about 50 mils from the end of the specimen at the tubing-armor interface, etching out the reaction. Masking the ends of the target prevented this attack.

CONCLUSIONS

These conclusions are a result of an evaluation of the beryllium hypervelocity targets fabricated at Battelle. The conclusions are based primarily on visual observations made during decanning, machining, and pickling of the targets.

(1) Gas-pressure-bonded beryllium armor around Type 316 stainless steel or niobium-1 weight percent zirconium tubing of different wall thickness was dense and appeared well bonded after processing at 1400°F for 1 hour at 10,000 psi.

(2) Both the powdered QMV beryllium and the hot-pressed extruded PX20 beryllium densified and bonded satisfactorily.

(3) Mild steel cans and end plugs were satisfactory for densifying the beryllium and were easily removed by nitric acid pickling.

(4) Hydrostatic pressing of powdered beryllium around the tubing and mandrel resulted in slight bowing of the target.

(5) The beryllium bright etch employed in this study was very successful.

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RECOMMENDATIONS

These recommendations are listed as a means to improve the method of assembly and fabrication of beryllium tube hypervelocity targets by the gas-pressure bonding process.

(1) Slight bowing (around 30 - 60 mils) of the targets after hydrostatic pressing could be eliminated by a more uniform packing of the beryllium powder around the tubing and mandrel. Some provision for alleviating end loading until the compact is at a higher density could also minimize bowing. A more extensive study of pressing techniques would be helpful in solving this problem.

(2) Hydrostatic pressing and extruding the beryllium to a larger initial starting OD would minimize surface indentations after final machining. Enough beryllium stock would then be present to machine out these indentations.

(3) Since the major objective of this study was to fabricate targets for hypervelocity testing, bonding parameters were not optimum. The quality of the bond should be investigated as a function of bonding conditions.

(4) The properties of the bond as a function of source material were not evaluated in this study. Depending upon test results obtained by NASA, this phase of the study should be more detailed.

The experimental data from this contract are recorded in BMI Laboratory Record Book No. 20460.

TABLE 1. ANALYSIS OF BERYLLIUM QMV POWDER

General Composition	Weight Percent
Be	99.5
BeO	0.58
Al	0.075
B	0.00008
Cd	<0.00007
Ca	<0.01
C	0.07
Cr	0.01
Co	0.0005
Cu	0.009
Fe	0.080
Pb	<0.001
Li	0.0001
Mg	0.012
Mn	0.0125
Mo	<0.002
Ni	0.014
N	0.02
Si	-0.02
Ag	0.005

TABLE 2. ANALYSIS OF HOT-PRESSED EXTRUDED BERYLLIUM TUBING

Chemical Composition	Analysis
Be	98.51 wt %
BeO	1.61 wt %
B	1.1 ppm*
Ag	5.0 ppm
Al	0.075 wt %
C	0.090 wt %
Ca	200.0 ppm
Cd	1.0 ppm
Cu	73.0 ppm
Co	5.3 ppm
Cr	73.0 ppm
Fe	0.149 wt %
Li	0.5 ppm
Mg	0.005 wt %
Mn	0.013 wt %
Mo	10.0 ppm
Ni	0.017 wt %
Pb	3.0 ppm
Zn	100.0 ppm

* ppm - parts per million.

TABLE 3. BERYLLIUM TARGET DESIGNATION

Item	Beryllium Cladding	Liner Material and Wall Thickness
1	QMV	Stainless steel - 10 mil
2	QMV	Stainless steel - 28 mil
3	QMV	Stainless steel - 49 mil
4	PX20	Stainless steel - 10 mil
5	PX20	Stainless steel - 28 mil
6	PX20	Stainless steel - 49 mil
7	QMV	Niobium - 10 mil
8	QMV	Niobium - 25 mil
9	QMV	Niobium - 40 mil
10	PX20	Niobium - 10 mil
11	PX20	Niobium - 25 mil
12	QMV	Niobium - 40 mil
Test bars	QMV	--
Test bars	PX20	--

One specimen each of Items 8, 9, and 10 did not achieve full density due to a can failure during the pressure bonding run.

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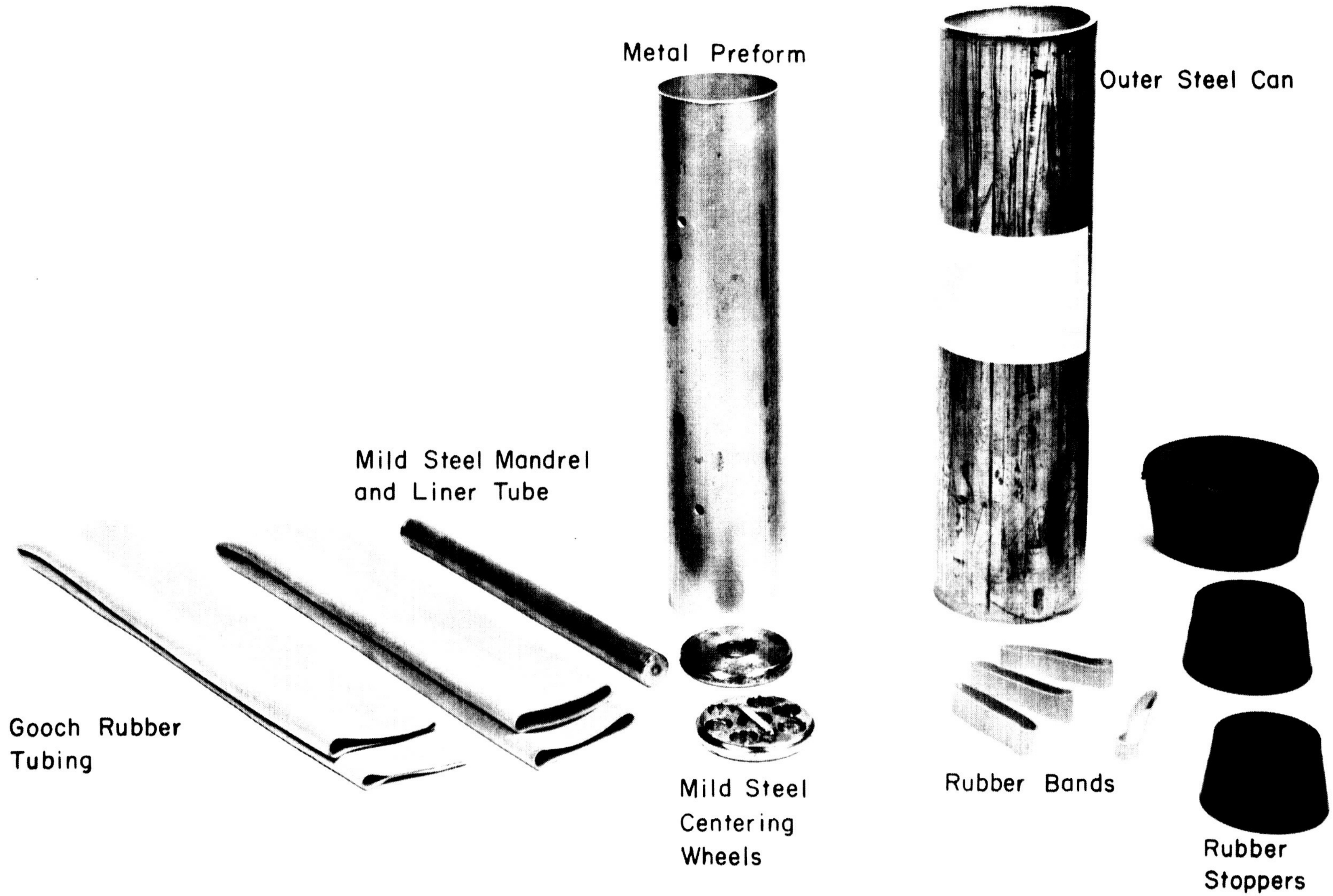

FIGURE 1. COMPONENTS EMPLOYED DURING THE HYDROSTATIC PRESSING OF BERYLLIUM QMV POWDER

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FIGURE 2. ASSEMBLED COMPONENTS PRIOR TO THE VIBRATORY COMPACTION OF THE BERYLLIUM POWDER

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FIGURE 3. HYDROSTATICALLY PRESSED BERYLLIUM SPECIMEN PRIOR TO MACHINING TO CAN SIZE

FIGURE 4. CANNED BERYLLIUM SPECIMEN READY TO BE PRESSURE BONDED

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FIGURE 5. EXTRUDED BERYLLIUM LINER TUBE, MANDREL, CAN AND END PLUGS PRIOR TO ASSEMBLY

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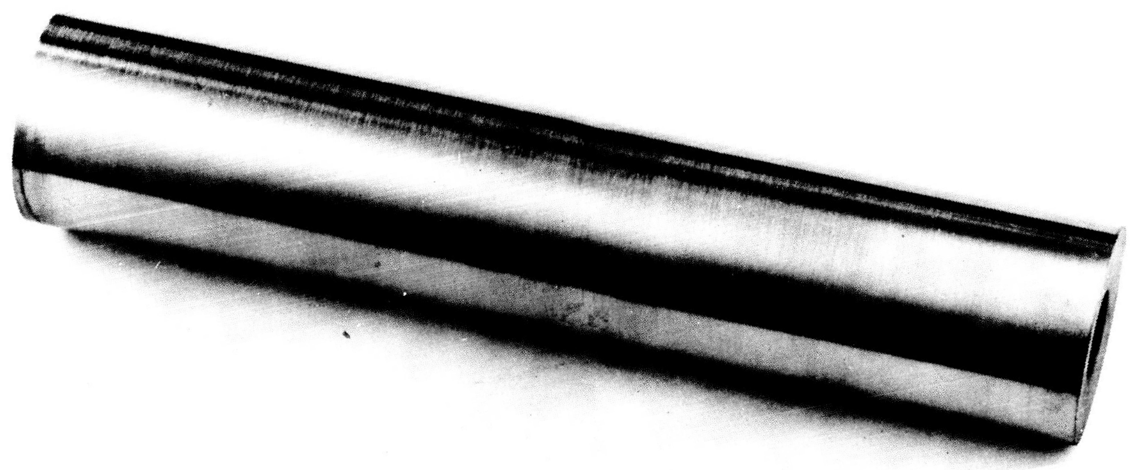

FIGURE 6. BERYLLIUM-CLAD HYPERVELOCITY IMPACT TARGET

Machined and polished to final size.

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FABRICATION OF BERYLLIUM-CLAD TUBULAR HYPERVELOCITY IMPACT TARGETS BY GAS PRESSURE BONDING

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ABSTRACT

Beryllium armor was gas pressure bonded to the circumference of 0.50 inch O.D. x 6 inch long tubing of both AISI 316 stainless steel and columbium-1% zirconium alloy. Nominal liner wall thicknesses of 10, 25, and 40 mils were employed. Successful bonds were achieved with beryllium powder, hydrostatically pressed and sintered under pressure and extruded annealed beryllium tubing. Process details are described but no attempts were made to optimize bonding parameters or analyze the bonds produced.

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